

CHAPTER SEVEN: SYNTHESIS AND CONCLUSIONS

7.1 Introduction

“Despite growing attention to how human activities alter plant communities, little is known about the ecosystem consequences of these changes” (Mayfield *et al.*, 2005)

Habitats all over the world have been destroyed and transformed by human inhabitation and activities (August *et al.*, 2002; Ojima *et al.*, 1994), and the Rand Highveld Grassland in the Tlokwe Municipal area, South Africa is no different. Nearly 50% of this vulnerable vegetation unit has been transformed, 3.2% is considered extensively degraded by urbanisation, agriculture, and mining (NWDACERD, 2009), whilst only 1% is actively being conserved (Mucina & Rutherford, 2006). Therefore expanding knowledge of the remaining Rand Highveld Grassland is of great importance towards the conservation, sustainable management, and persistence of this productive and species rich vegetation unit.

The main objective for this study was to investigate the influence of varying degrees of urbanisation in the landscape matrix (determined by urbanisation measures – matrix variables) surrounding selected grassland fragments, on the plant species diversity, plant functional diversity, and fine-scale biogeochemical landscape function (intra-patch variables) of the selected grassland fragments situated in and around the city of Potchefstroom, Tlokwe Municipal area, South Africa.

In this final chapter plant diversity-biogeochemical landscape function relationships will be explored, followed by an overview of the methods used and the key results obtained during this study. Synthesis and final conclusions on the various aspects under observation in the selected grassland fragments, namely plant species diversity, plant functional diversity, and fine-scale biogeochemical landscape function, were provided, and recommendations on further research, and management– and conservation practices were made.

7.2 Exploring “plant diversity-biogeochemical function” relationships

Studies on the links between biodiversity and ecosystem function predominantly examine aspects such as aboveground biomass (McNaughton, 1977; Kutiel & Danin, 1987, Tilman & Downing, 1994; Naeem *et al.*, 1995; Hooper & Vitousek, 1997; Wardle *et al.*, 1997; Symstad *et al.*, 1998), entailing that biodiversity is viewed as an „insurance policy“ against ecological perturbation, maintaining biological communities in the face of disturbance and environmental change (McNaughton, 1977; Pimm, 1984; Schulze & Mooney, 1993; Tilman *et al.*, 1998). Exotic species have also been found to

greatly affect ecosystem processes, especially nutrient cycling processes, because they grow fast and their litter decomposes quickly (Ehrenfeld, 2003).

Fine-scale biogeochemical function, which comprises soil surface stability, infiltration capacity, nutrient cycling, and the fine-scale landscape heterogeneity that promotes functional resource-conserving landscapes, has not been associated with plant species richness or plant functional diversity. The implications of this are that there is no evidence that a plant diversity-biogeochemical function relationship exists and what the nature of such a relationship may be. During LFA (landscape function analysis (Tongway & Hindley, 2004b) soil surface indicators such as the presence of plant aerial and basal cover that may protect soil particles and resources from erosion; the soil properties that may reflect the infiltration capacity of nutrients and water; and the soil crust condition and the presence of plant litter to reflect the nutrient cycling potential are assessed (Tongway & Hindley, 2004b)). Additionally the important role vegetated patches play in landscapes (regardless of plant species) by capturing and utilising resources such as water, nutrients, and soil sediments is acknowledged (Ludwig *et al.*, 2001). LFA results are thus convenient indicators of whether landscapes are functional and self-sufficient or dysfunctional (leaky) (Bastin *et al.*, 2002).

In this study fine-scale biogeochemical landscape function was concretely *quantified* using LFA and compared to plant species diversity and functional diversity, therefore possibly providing a new insight into the quantification of biodiversity-ecosystem function relationships. It was attempted to find relationships between plant species– and functional diversity and biogeochemical landscape function as determined by LFA. In other words, do the types of species and their suite of traits influence fine-scale biogeochemical landscape function in selected grassland fragments in the Tlokwe Municipal area?

Because LFA emphasises the importance of vegetated patches in fulfilling the role of obstructions to overland flow so as to prevent erosion and capture vital resources such as nutrients and water (Ludwig *et al.*, 2001), and does not discriminate between different plant species, one expects that plant species diversity, plant functional diversity and specific plant traits will not have any significant effects on fine-scale biogeochemical landscape function (as determined by LFA).

A correlation matrix and multiple regression analysis were executed in STATISTICA (version 10) (StatSoft, Inc., 2011) to express possible relationships between plant species– and functional diversity and fine-scale biogeochemical landscape function (Appendix L), significant correlations and linear relationships are provided in Table 7.1.

The significant correlations ($p < 0.05$) between plant species– and functional diversity and fine-scale biogeochemical landscape function presented in Table 7.1 indicate moderate ($r^2 \geq 0.1$) correlations that entail possible linear relationships. Some of the correlations (e.g. soil surface stability–

%hemicryptophyte, LOI–Pielou’s evenness index, and patch width–non-clonal - Table 7.1) bordered on r^2 values of 0.25 indicating practically significant linear trends. Although some significant relationships between landscape functionality variables and plant species– and functional diversity and plant functional traits became evident, these relationships are not easily explained. For instance the LOI (percent of the gradsect sampled in LFA that consisted of vegetated, resource-conserving patches) increased with decreasing mean percentage succulents (Table 7.1). There is no apparent reason for this trend and it might be considered that correlating these variables has no practical application.

Other correlations that may be explicable, but does not really inform us on the nature of plant diversity–biogeochemical landscape function relationships in the study area, are present. For example soil surface stability correlated with mean percentage hemicryptophytes (Figure 7.2). Hemicryptophytes recorded in the study area were primarily grass species. Grass patches (GP’s) were found in *Chapter 6* to be one of the patch types that provided the landscape with the highest soil surface stability. Therefore it may be observed that the stability SSA index increases when a higher percentage of the total plant species richness consists of hemicryptophytes. A moderate linear relationship ($0.1 \leq r^2 \leq 0.25$) between soil surface stability and % hemicryptophytes indicates a possible practical, but not concrete, correlation between these variables.

Although moderate correlations between elements of landscape function (as determined by the LFA method) and certain aspects of plant diversity and functional diversity, especially the specific plant traits, became evident (Table 7.1), it cannot be said that the plant species– and functional diversity of selected grassland fragments in the Tlokwe Municipal area determined or influenced the fine-scale biogeochemical landscape function. This result supports the hypothesis that plant species diversity, plant functional diversity and specific plant traits will not have any significant effects on fine-scale biogeochemical landscape function (as determined by LFA).

Species diversity have been found to contribute to ecosystem functioning in providing resistance and resilience to disturbance (Chapin *et al.*, 1995; Loreau *et al.*, 2001; McNaughton, 1977; Pimm, 1984; Schulze & Mooney, 1993; Tilman *et al.*, 1998), and primary production (Loreau *et al.*, 2001; Reich *et al.*, 2004; Wilsey & Potvin, 2000). In this final chapter the aim was to explore and explicitly test whether plant species diversity, plant functional diversity and specific plant traits influence fine-scale biogeochemical aspects of ecosystem function (namely soil surface stability, infiltration capacity, and nutrient cycling potential). No such definite relationships were expressed, as the LFA method does not discriminate between different plant species or their functional traits. In other words, an exotic plant may form a vegetated patch that provides the system with physical soil protection, captures water, nutrients and soil particles for infiltration into the system, and creates soil surface conditions favourable for active nutrient cycling processes. It is, however, important that from a conservation

point of view, ecosystem function of the fragmented grasslands should be dependent on native species (Schwartz *et al.*, 2000). In other words: exotic species cannot be a conservation priority over native species, even if the exotic species fulfil successful roles in enhancing biogeochemical landscape function. The LFA method accentuates the importance of vegetated patches in controlling overland flow, thus preventing erosion and providing opportunity for vital resources to infiltrate the soil and remain within the system (Ludwig *et al.*, 2001; Tongway & Hindley, 2004b), therefore apparent relationships, and/or the lack thereof, between biogeochemical landscape function and plant species diversity cannot be explained easily for this study, and currently, without further research there is no reason to believe that such relationships exist.

Table 7.1: Correlation matrix and multiple regression results for LFA variables and plant species diversity. Only significant correlations ($p < 0.05$) are indicated. Correlation directions are indicated in grey and moderate linear relationships ($0.1 \leq r^2 < 0.25$) in orange.

			Corr. direction	r ² value
Fine-scale landscape attributes	LOI	Shannon's diversity index (H')	-	0.1914
		Pielou's evenness index (E)	-	0.2428
		%Succulent	-	0.1616
		%Semi-evergreen	-	0.2251
	Total patch area (m ²)			
		Functional dispersion (FDis)	+	0.1388
	Patch width (cm)			
		%Geophytes	+	0.1700
		%Non-clonal	-	0.2447
		%Clonal belowground	+	0.2046
LFA soil surface parameters	Soil surface stability			
		%Hemicryptophyte	+	0.2353
		%Deciduous	+	0.1600
	Infiltration capacity			
		%Chamaephyte	-	0.1605
		%Semi-evergreen	-	0.1489
	Nutrient cycling			
		%Trees	-	0.1322
		%Chamaephytes	-	0.1556
		%Deciduous	+	0.1394
		%Semi-evergreen	-	0.1870
	Total SSA functionality			
		%Hemicryptophyte	+	0.1605
		%Deciduous	+	0.1600
		%Semi-evergreen	-	0.1752

For future studies in explicitly expressing relationships between fine-scale biogeochemical landscape function and plant species- and functional diversity, it may be recommended that the LFA approach be adjusted. Although LFA does not differentiate patches and interpatches on a species level, but rather focuses on the fine-scale functionality of a system, it would be interesting to determine the soil surface functionality of individual plant species. For instance, identifying different plant species as

different patch types (e.g. *Themeda triandra*-patch, *Acacia karroo*-patch), although this in turn poses new challenges in terms of patch delineation as vegetation may grow intertwined, and exotic species often “invade” into patches of native vegetation.

7.3 Quantification of an urbanisation gradient

“The growing impact of urban areas on the face of the earth is reason enough to study them.”
(Grimm *et al.*, 2000)

The first step towards determining the effects of urbanisation on plant diversity and landscape function was to classify a SPOT 5 (CNES, 2007) satellite image into five land cover types to ultimately create a land cover map which was used as input to calculate urbanisation measures for quantification of an urban-to-rural gradient. This was done by executing GIS techniques using ArcMap 10 software (ESRI, 2010). Spatial metrics have been a proven practical tool for quantifying the spatial heterogeneity of landscapes at various scales (Herold *et al.*, 2005), and pattern-process relationships have driven the demand for effectively quantifying the structure of, and the processes within, landscapes (Gustafson, 1998).

7.3.1 Key results overview

The 421 RGB band combination of the SPOT 5 satellite image was visually determined to be the most appropriate band combination for further land cover classification, and was successfully classified into five land cover types, namely water, trees, grass, urban and soil, with an overall accuracy of 87%. The resulting land cover map was subsequently overlaid by a total of 5846 500 m² grid cells and used to calculate urbanisation measures that would describe human impacts in the matrix area surrounding the selected grassland fragments.

The urbanisation measures used by Hahs and McDonnell (2006) and Du Toit (2009) were tested and eight applicable metrics were selected for the purpose of this study. The spatial metrics were subsequently calculated for each 500 m² grid cell and statistically analysed with a factor analysis (FA). With specific research questions kept in mind, the FA facilitated the selection of four applicable and comprehensible spatial metrics that further described the urbanisation gradient within the study area (Table 7.2). Each urbanisation measure acted as an indicator for processes and patterns associated with urban areas. Urban areas are characteristically fragmented (Collinge, 1996; August *et al.*, 2002), contains impervious surfaces (e.g. built-up areas) (McDonnell & Pickett, 1990; Niemelä, 1999; Pickett *et al.*, 2001), are inhabited by more people than surrounding rural areas (United Nations Population Fund, 2011), and cause the transformation and loss of natural grasslands (Fairbanks *et al.*, 2000; Grobler *et al.*, 2006; Matsika, 2007; Scholes & Biggs, 2005).

Table 7.2: The four selected urbanisation measures used to quantify an urbanisation gradient in the study area and the processes / patterns associated with urban areas which they represent.

Urbanisation measure	Process/pattern associated with urban areas
Density of people (DENSPEOP)	Urbanisation
Edge density (ED)	Fragmentation
Percentage grass land cover (PGRALC)	Rand Highveld Grassland habitat loss
Percentage urban land cover (PURBLC)	Percentage impervious surfaces

The selected four urbanisation measures were subsequently calculated for the 500 m radius matrix area surrounding the boundary of each selected grassland fragment. Based on the four selected urbanisation measures the 30 selected grassland fragments were objectively classified into two urbanisation classes, namely “rural/peri-urban” and “urban”, using a cluster analysis to determine their position along the urbanisation gradient. From this section of the study it was also found that the city of Potchefstroom does not conform to conventional urban morphology characterised by concentric zones of different land use types and urbanisation intensities radiating outwards from the CBD as described by Burgess (1925).

The urbanisation measure values for the matrix area surrounding each selected grassland fragment were available for statistical input in determining possible linear relationships between intra-patch variables (plant species– and functional diversity, and landscape function) and degree of urbanisation, whilst the classification of the selected grassland fragments into two urbanisation classes allowed for determining statistically significant differences between intra-patch variables of rural/peri-urban and urban grassland remnants.

7.4 Plant species richness and functional diversity

“...in aiming to protect natural ecosystems, we cannot just manage for „species diversity” alone – as measured by richness or the Shannon-Wiener index, which ignores species composition. The functional characteristics of the component species in any ecosystem are likely to be at least as important as the number of species for maintaining critical ecosystem processes and services.” (Hooper & Vitousek, 1997)

Plants are extremely important for maintenance of life on earth, and provides an array of goods (i.e. food and shelter) and services (i.e. oxygen production through photosynthesis and climate regulation) from which humans benefit (Henry, 2005). Also, morphological and physiological plant traits may provide clues to environmental pressures or change (Gitay & Noble, 1997; Lavorel *et al.*, 1997; Lavorel & Garnier, 2002; Shugart, 1997; Walker *et al.*, 1999), and even influence the environment in which they exist (Gitay & Noble, 1997; Lavorel *et al.*, 1997; Lavorel & Garnier, 2002; Shipley, 2010; Shugart, 1997).

Functional diversity indices provide a tool towards an easier way to determine functional diversity (Petchey *et al.*, 2009), and describe the extent and manner in which species are distributed throughout a hypothetical functional niche space (Schleuter *et al.*, 2010).

7.4.1 Aim and hypotheses

In this section of the study, plant species in 79 sample plots in the 30 selected grassland fragments were recorded, and nine plant functional traits (Aronson, 2007; Cornelissen *et al.*, 2003) for each species were described. The final goal was to quantify plant species richness, species diversity indices, plant functional trait composition, and functional diversity indices. These factors of plant species diversity were then brought into context with the urbanisation gradient (see 7.3: *Quantification of an urbanisation gradient*), in order to determine whether the degree of human impacts (expressed by the four urbanisation measures) in the matrix surrounding the grassland fragments impacted the plant species within the grassland fragments.

The hypothesis for this section of the study was that selected grassland fragments situated in matrix areas exposed to increased human impacts (urban matrix) will 1) have higher plant species diversity; 2) contain more exotic species; 3) support different proportions of plant traits; and 4) have higher plant functional diversity than rural/peri-urban grassland fragments.

7.4.2 Key results overview

A total of 350 species, of which 24% were exotic, were recorded in the selected grassland fragments in the Tlokwe Municipal area. Plant species richness, Shannon's diversity index and Pielou's evenness index varied greatly for the 30 selected grassland fragments within the Tlokwe Municipal area. Urban grassland fragments had lower mean plant species richness, Shannon species diversity (significantly), and Pielou species evenness than rural/peri-urban grassland fragments. These results are not consistent with popular findings that species richness increase in urban areas (Deutschewitz *et al.*, 2003; Klotz, 1990; McKinney, 2002; Pyšek & Pyšek, 1990; Rebele, 1994; Stadler, *et al.*, 2000; Thuiller *et al.*, 2006), but coincides with the results from Potchefstroom's neighbouring town Klerksdorp (Du Toit, 2009). Therefore, the first hypothesis for this chapter that selected grassland fragments situated in matrix areas exposed to increased human impacts will have higher plant species diversity was not supported by the results of this study.

Significantly higher mean percentage exotic species in urban areas supported the second hypothesis for this section: that selected grassland fragments situated in matrix areas exposed to increased human impacts will contain more exotic species. It was indicated by several other studies that urban areas are generally characterised by high non-native species richness (Niemelä, 1999; Pickett *et al.*, 2011; Pyšek, 1998). Significant correlations ($p < 0.05$) were found between the four urbanisation measures and mean percentage species of the total species richness possessing certain functional

attributes. This indicated that increased urbanisation (higher PURBLC, ED, DENSPEOP and lower PGRALC – matrix variables) may influence the species composition and the occurrence of specific functional traits in the selected grassland fragments. However, even though some statistically significant differences between the prevalence of certain plant traits characterising plant species in rural/peri-urban and urban grassland fragments became evident, it cannot be confirmed that the degree of urbanisation / human impact in the matrix surrounding grassland fragments determines the occurrence or persistence of the types of plant species possessing certain functional attributes, based on the type of functional traits used. This entails that the third hypothesis for this section of the study that selected grassland fragments situated in matrix areas exposed to increased human impacts (urban matrix) will support different proportions of plant traits than rural/peri-urban grassland fragments, was not supported.

The functional diversity indices (FRic, FEve, FDiv, FDis, FSpe) did not show significant variation between the urbanisation classes, and no statistically significant differences were found between FRic, FDiv, FDis, and FSpe of selected rural/peri-urban and urban grassland fragments. This may be a legacy of the nature of the traits selected for this study, in that every site may contain species that possess most combinations of traits. Urban grassland fragments, however, had significantly higher FEve than rural/peri-urban grassland remnants. Similar results were found in the studies of Biswas & Malik (2010) and Pakeman (2011). Increasingly disturbed plant communities may contain species with similar abundances that are distributed regularly along functional trait gradients, indicating that competition may shape community structure at lower levels of disturbance, and not so much at higher disturbance intensities (Pakeman, 2011). Functional Evenness (FEve) correlated with PURBLC in the matrix and showed a moderate linear relationship, where FEve increased with percentage impervious surfaces. No statistically significant differences were found between the functional diversity indices of the selected rural/peri-urban and urban grassland fragments (except for FEve, as mentioned above), indicating that it is not only the degree of urbanisation in the matrix area surrounding grassland fragments that determines the plant functional diversity (based on the selected traits) in the Tlokwe Municipal area. This result did not support the third hypothesis that selected grassland fragments situated in matrix areas exposed to increased human impacts will have higher plant functional diversity.

7.4.3 Recommendations

It may be recommended that exotic “keystone” species be removed to prevent them from potentially becoming invasive. Exotic plant species such as *Araujia sericifera* and *Melia azedarach* have a unique set of functional traits, providing them with the ability to utilise resources in an ecosystem that are underutilised by other species, and therefore they are already regarded as declared weeds and invaders in South Africa (Conservation of Agricultural Resources Act (43 of 1984); Henderson,

2001). Other species such as *Alternanthera pungens* and *Medicago laciniata* also have a unique set of functional traits and may establish and persist as biotic invaders, possibly become invasive and eventually alter ecosystem functioning. Future research focusing on temporal exotic invasion and disturbance dynamics, as well as functional attributes that may determine the exotic invasion success of a species, might be able to determine whether the functional diversity of the selected grassland fragment provide insurance against biotic and physical perturbations.

The selection of applicable functional traits towards addressing certain research questions is extremely important. Petchey *et al.* (2009) indicated that “*the choices of traits may hold more sway than the choice of a functional diversity index.*” The timeframe of this study called for easily measured, “soft” life-history traits, which may have resulted in insignificant variation in the functional diversity indices, possibly due to the fact that each site contained combinations of species that have similar suites of traits. It may be proposed that different traits be selected in future studies of the Rand Highveld Grassland in order to determine which plant functional traits are being impacted by urbanisation, and might be more meaningful in terms of biodiversity-ecosystem functioning research of urban environments. For instance Kardel *et al.* (2010) found stomatal characteristics such as stomatal pore surface and –density as possible effective indicators of the quality of urban ecosystems. However, the results of Duncan *et al.* (2011) indicated that urban areas do not filter native species with specific functional traits, in other words species with certain traits are not necessarily more vulnerable to extinction in urban areas.

7.5 Landscape functionality

“LFA can identify critical missing processes in dysfunctional landscapes in many land-use applications...” (Tongway & Hindley, 2004a)

Landscape Function Analysis (LFA) is concerned with 1) the conservation and loss of vital resources such as soil particles, water, and nutrients from a landscape; and 2) soil surface properties that reflect the soil surface stability, infiltration capacity, and nutrient cycling potential of a landscape (Tongway & Hindley, 2004b). Vegetated patches (i.e. grass patches, forb patches, litter patches) play important roles in capturing resources that are being transported by water and wind, thereby preventing soil erosion and creating soil conditions that allow the system/landscape to be self-sustaining (Ludwig *et al.*, 1999a, 1999b, 2005; Ludwig and Tongway, 1995; Schlesinger *et al.*, 1996; Vásquez-Méndez *et al.*, 2010).

7.5.1 Aim and hypotheses

The aim of this section of the dissertation was to apply the LFA method in the selected grassland fragments, and use the physical landscape – and soil surface attributes data to determine the fine-scale

biogeochemical landscape functionality of the selected grassland fragments within the study area. In order to determine whether the intensity of urbanisation in the matrix surrounding the grassland fragments has an effect on fine-scale biogeochemical landscape function within the grassland remnants, possible patterns of physical landscape attributes and soil surface functionality across an urban-rural gradient were also explored.

The hypotheses for this part of the study were that selected grassland fragments situated in matrix areas exposed to increased human impacts 1) will be characterised by a fine scale landscape structure that is diagnostic of a system that are not actively capturing and conserving vital resources such as soil particles, water and nutrients; and 2) will have lower stability, infiltration and nutrient cycling soil surface indices, resulting in lower total SSA functionality, than rural/peri-urban areas.

7.5.2 Key results overview

The LFA results indicated that the presence and size of vegetated patches, as well as vegetation litter abundances were driving the differences in the functionality indices. Less and smaller interpatches, and wide vegetated patches (physical landscape attributes) played important roles in contributing to the three functionality indices namely stability, infiltration, and nutrient cycling.

No statistically significant differences between the physical landscape attributes for rural/peri-urban and urban selected grassland fragments were evident. Also the urbanisation measures describing the matrix surrounding the grassland remnants, and the physical landscape attributes did not correlate, entailing that the degree to which the landscape surrounding a grassland fragment is urbanised does not have an effect on the fine-scale patch characteristics that allow for a landscape to either conserve or lose resources. This result did not support the first hypothesis of this LFA section.

Rural/peri-urban grassland fragments had higher infiltration capacity, nutrient cycling potential, and total SSA functionality (although not significantly), which may be ascribed to differences in management practices, such as mowing in more urban areas and grazing and fire in more rural areas. In the mown selected urban grassland fragments litter was often not removed, creating vast litter patches that substantially contributed to the SSA indices of these areas. Furthermore, the presence of fire in rural grassland fragments may remove litter from the soil surface, resulting in lower surface litter cover, but also returns nutrients into sub-surface soil layers (Boerner, 1982; Marañón-Jiménez & Castro, 2013; Tongway & Hodgkinson, 1992). However, the second hypothesis that selected grassland fragments situated in matrix areas exposed to increased human impacts will have lower stability, infiltration and nutrient cycling soil surface indices, resulting in lower total SSA functionality, was also not supported, due to the fact that all grassland remnants situated in more urbanised matrix areas did not consistently have the lowest stability, infiltration, nutrient cycling, and total SSA functionality values. Moderate linear relationships were found between PURBLC and

PGRALC (matrix variables) and the infiltration capacities (intra-patch variable). Although these linear relationships exist, they are only moderate, indicating possible (not absolute) trends.

The results suggest that it is not necessarily the influence of an surrounding urban matrix leading to high or low resource conserving patchiness and patch quality, but rather the management practices of grassland fragments associated with high (more urban – subjected to mowing) or low (more rural – subjected to grazing and fire) urbanisation influencing the landscape function. In the more urbanised areas higher patch quality (litter abundances due to mowing and the presence of annual plant species recorded as litter) compensates for lower patch size.

In conclusion, anthropogenic disturbances (urbanisation processes) in the matrix surrounding the selected grassland fragments in the Rand Highveld Grassland have no direct negative effect on the fine-scale functioning within grassland remnants. This is a clear indication that these “urban” grasslands are just as conservable (on a biophysical function level involving soil processes) than their more “rural” or “natural” counterparts.

7.5.3 Recommendations

According to Gustafson (1998), *“the successful application of research findings depends critically on both identifying the appropriate scale for the application and the ability to extrapolate findings across scales.”* Recognising the appropriate scale at which characteristics of the urban matrix may have an influence on fine-scale biogeochemical landscape functionality is the key to developing land use- and conservation plans. LFA parameters (that characterises fine-scale biogeochemical function within the grassland fragments) and urbanisation measures (that describes the degree of urbanisation / human impact in the matrix surrounding the grassland fragments) were correlated, yet no empirical evidence that the quality of the matrix surrounding a habitat patch may influence fine-scale biogeochemical landscape function or the scale on which it may relate, exists. It is therefore difficult to describe any matrix quality and landscape functionality relationships as direct or causal. But this study may form the first step and basis for further investigations into whether or not such relationships exist.

LFA may not necessarily have been the most effective tool to use for determining differences in landscape function of the selected grassland fragments, as the variance between the “best” and the “worst” sites was not significant, possibly due to anthropogenic aspects, such as mowing, compensating for the occurrence of less and smaller resource-conserving patches. Although mowing may be seen as a “non-natural” management practice and an anthropogenic disturbance, the litter is predominantly left within the system, and not removed (as is the case in areas that are grazed and burnt), which will enhance the SSA indices values in an “unrealistic” manner in comparison to grasslands that are not mown. From the LFA results obtained in this study, as well as other studies (Haagner, 2008; Van der Walt, 2012), the presence, origin, and degree of decomposition of litter has

been identified as main factors in determining the LFA functionality indices. LFA records the presence of litter on the soil surface, as well as its degree of decomposition, but how effectively the litter is decomposed by means of soil faunal and microbial activity, and returned into the soil are still not fully understood, especially not in urban areas (Vauramo & Setälä, 2011). Plant litter in urban areas has been found to decompose at increased rates (McDonnell *et al.*, 1997; Pouyat *et al.*, 1997; Vauramo & Setälä, 2011), but may also be of poorer quality than litter found in rural areas (McDonnell *et al.*, 1997). Future research on plant litter quality and decomposition, as well as soil faunal activity to determine the successful feedback of nutrients into the soil of grassland fragments across urban-rural gradients may contribute to better understanding soil process dynamics in urban ecosystems.

7.6 Summary

“Biodiversity and ecosystem functioning research can and should supply managers, conservation biologists, policy makers, and other interested parties, with the information they need to make the best decisions they can regarding their effects on biodiversity” (Naeem *et al.*, 2009)

Urban and rural/peri-urban grassland fragments in the Rand Highveld Grassland situated in the Tlokwe municipal area, South Africa, may be considered for conservation purposes. Although the grassland remnants in the urban areas are predominantly smaller (size (ha) range (urban) = 0.59 – 18.13 vs. size (ha) range (rural/peri-urban) = 3.76 – 179.41), both small and large habitat patches bear ecological importance (Forman, 1995). Smaller Rand Highveld Grassland fragments (as found in the Potchefstroom city urban areas) may act as “stepping stones” for the dispersal of species and may be characterised by high species densities; whilst larger Rand Highveld Grassland remnants (as found in the rural/peri-urban areas of the Tlokwe Municipal area) may support sustainable population sizes, and contain microhabitat conditions providing habitat for an array of species (Forman, 1995).

This study contributed towards knowledge on plant diversity and also explored the use of functional diversity indices to describe the plant functional diversity of grassland fragments in the Tlokwe Municipal area. Current knowledge indicates that Landscape Function Analysis (LFA) was used in an urban context in this study for the first time in South Africa, and aided in describing the state of fine-scale patchiness and soil surface processes of urban grassland remnants in relation to rural/peri-urban grassland fragments. This is also the first time that the relationship between matrix conditions surrounding a habitat patch and fine-scale biogeochemical landscape function within the habitat patch was explored. Further research on this subject must be carried out in order to confirm or deny a causal association between the two above mentioned parameters. Possible relationships between fine-scale biogeochemical landscape function and plant species diversity were also researched, anticipating contributions to diversity–ecosystem function research. The LFA method does not discriminate

between different plant species, but rather records the role of vegetated patches as obstructions to overland flow, preventing erosion and capturing vital resources such as nutrients and water (Ludwig *et al.*, 2001). Therefore, the results show that a high diversity of plant species and plant functional traits does not necessarily contribute to high soil surface stability, infiltration capacity, nutrient cycling potential and total soil surface functioning.

From a conservation perspective, this study indicates that urbanisation and its associated patterns and processes (i.e. fragmentation and habitat loss) within the Tlokwe Municipal area does, to some extent, influence plant species diversity, plant functional trait composition, and plant functional diversity. However, the insufficiency of consistent strong statistical effects indicated that the plant species diversity and functional composition of rural/peri-urban and urban grassland fragments are not considerably different, suggesting that all Rand Highveld Grassland fragments in the Tlokwe Municipal area may bear conservation importance. Urbanisation might have an effect on fine-scale landscape heterogeneity and soil surface biogeochemical functioning (as determined by LFA) of the selected grassland fragments, but the management practice of specifically mowing in some urban grassland remnants may have compensated for a less resource-conserving fine-scale landscape structure, resulting in higher soil surface functioning.

In conclusion, grasslands in an urban landscape matrix are just as conservable as rural/peri-urban grassland fragments. The protection of these grassland remnants, which are often regarded as being degraded and transformed beyond conservation status, may contribute to the persistence of the endangered Rand Highveld Grassland vegetation unit. However, despite the fact that fine-scale biogeochemical landscape function of urban and rural/peri-urban landscapes are comparable, differences in plant species diversity, functional trait composition, and plant functional diversity was evident. The presence of significantly higher mean percentage exotic species in urban areas indicated that urban grassland fragments have undergone extensive biotic invasions, bringing into question the conservation potential of these grassland remnants and also indicating the need for management and prevention of exotic plant species encroachments.

Furthermore, fine-scale biogeochemical function of some of the “more functional” urban grassland fragments has been artificially enhanced by the “non-natural” management practice of mowing. The questions that arise from this are:

- Should the “non-natural” management practice of mowing in urban grassland fragments then also be conserved?
- How would mowing affect the landscape function of urban grassland fragments that are not subject to mowing?

- If mowing of these urban grassland fragments is discontinued will the stability, infiltration, nutrient cycling LFA indices and total SSA functionality of these areas decrease?
- Will the selected urban grassland fragments still be a conservation opportunity if mowing has ceased and fine-scale biogeochemical landscape function has decreased?

In urban ecosystems humans and nature are integrated. Humans modify their environment to best suit their current needs, such as mowing of urban grasslands for aesthetic purposes. If cities are to be viewed as entirely separate and unique ecosystems, the dynamics thereof should be viewed as “natural” to that ecosystem. For instance, urban grassland fragments should continue to be mown, but the protection and promotion of native species in urban areas must be a priority. Additionally the introduction of exotic species characterised by certain functional traits enabling them to exploit unused resource strata (e.g. trees, annuals, and species with aboveground clonal growth) and exotic “keystone” species (e.g. *Araujia sericifera*, *Guilliminea densa*, *Melia azedarach* and *Pinus* species) must be limited.

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7.7 References

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